PB88-144316

Effect of Low Level Carbon Monoxide on Compensatory Tracking and Event Monitoring

North Carolina Univ. at Chapel Hill

Prepared for

Health Effects Research Lab.
Research Triangle Park, NC

1987

U.S. Department of Commerce
National Technical Information Service

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before comple

1. REPORT NO.	2.	3. PB88-144316
EPA/600/J-87/130		

4. TITLE AND SUBTITLE	5. REPORT DATE
EFFECT OF LOW LEVEL CARBON MONOXIDE ON COMPENSATORY TRACKING AND EVENT MONITORING (Journal Version)	1987
	6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Vernon A. Benignus[1,4], Keith E. Muller[2], Curtis N. Barton[3], and James D. Prah[1]	

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
1. U.S. Environmental Protection Agency & Dept. of Psychology 2. Department of Biostatistics, UNC 3. Dept. of Psychology, UNC	11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Health Effects Research Laboratory, RTP Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711	14. SPONSORING AGENCY CODE EPA/600/11

15. SUPPLEMENTARY NOTES

Neurotoxicology and Teratology, Vol. 9, pp. 227-234

16. ABSTRACT

Experiments by Putz et al. [6,7] concerning the effect of carbon monoxide (CO) exposure on compensatory tracking and monitoring in healthy young men were replicated. Task and procedural variables were reproduced as closely as practical. Subjects were exposed to either room air or 100 ppm CO. Mean carboxyhemoglobin (COHb) levels in the high CO exposure groups were 5.1% for Putz et al. [6]] (70 ppm exposure), and 8.24% for the present study (100 ppm exposure). In both studies elevated COHb produced a statistically significant increase over time in log mean absolute deviation scores (tracking error) with respect to control groups. The magnitude of the effect was smaller in the present study, perhaps because of subtle methodological or training differences between studies. The relationship between task difficulty and magnitude of CO-induced dysfunction remains unresolved.

In contrast to Putz et al. [6], no statistically significant effect of COHb in monitoring behavior was found. The failure to replicate this feature of [6] may reflect the large differences in baseline performance, and higher variance in the present study.

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

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EPA/600/J-87/130
JOURNAL ARTICLE

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Effect of Low Level Carbon Monoxide on Compensatory Tracking and Event Monitoring[1]

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Received 6 November 1986

BENIGNUS, V. A., K. E. MULLER, C. N. BARTON AND J. D. PRAH. *Effect of low level carbon monoxide on compensatory tracking and event monitoring.* NEUROTOXICOL TERATOL 9(3) 227–234, 1987.— Experiments by Putz *et al.* [6,7] concerning the effect of carbon monoxide (CO) exposure on compensatory tracking and monitoring in healthy young men were replicated. Task and procedural variables were reproduced as closely as practical. Subjects were exposed to either room air or 100 ppm CO. Mean carboxyhemoglobin (COHb) levels in the high CO exposure groups were 5.1% for Putz *et al.* [6] (70 ppm exposure), and 8.24% for the present study (100 ppm exposure). In both studies elevated COHb produced a statistically significant increase over time in log mean absolute deviation scores (tracking error) with respect to control groups. The magnitude of the effect was smaller in the present study, perhaps because of subtle methodological or training differences between studies. The relationship between task difficulty and magnitude of CO-induced dysfunction remains unresolved. In contrast to Putz *et al.* [6], no statistically significant effect of COHb in monitoring behavior was found. The failure to replicate this feature of [6] may reflect the large differences in baseline performance, and higher variance in the present study.

Carbon monoxide Carboxyhemoglobin Compensatory tracking Monitoring Vigilance

THE extent to which exposures to low levels of carbon monoxide (CO) produces neurobehavioral dysfunction is not well known. Several studies have reported that exposure to low levels of CO does produce behavioral dysfunction but such findings have been difficult to replicate [1,3]. Failure to replicate findings could be due to (a) low level exposures which were near threshold for effects, (b) unreliable performance of human subjects on the tasks chosen for study, (c) changes of procedure in replication studies with respect to the original studies, (d) lack of double blind design, or (e) type I errors which were reported, in contrast to nonsignificant findings which are typically not reported [8].

Putz *et al.* [6,7], reported and separately replicated a study of the effects of CO in non-smoking subjects (20 males and 10 females) upon (a) tracking, (b) monitoring, and (c) auditory evoked potentials. The tracking task involved keeping a moving spot centered on a cathode ray tube (CRT) by manipulating a joystick. The monitoring task was performed simultaneously with tracking and consisted of detecting bright flashes of light interspersed among a series of dimmer flashes. The subject's task was to detect the bright flashes. The auditory evoked potential task consisted of listening to a series of tones presented serially and pressing a button when a one KHz target tone was presented. Non-target tones were either higher or lower in frequency.

Subjects were 24 healthy males who had never smoked (self report) except for one control subject who had been a non-inhaling pipe smoker until about 10 years before the experiment. In the first study, an independent group of subjects served at each exposure level [6]. In the second study, each subject served in all exposure levels [7]. The 70 ppm group reached about 5 percent carboxyhemoglobin (COHb) at the end of the 4 hour exposure.

In both studies, the 70 ppm group showed statistically significant decrements in tracking accuracy. The amount of decrement increased as a function of time of exposure. Latency of detection on the light flash task also was significantly increased by 70 ppm CO exposure in a time-on-task related fashion. No effect of 35 ppm CO exposure was observed. The evoked potential was not affected by any CO level, at any time.

The Putz *et al.* study [6] is important for two reasons.

[1]This research was partly funded by the U.S. Army Medical Research and Development Command, Ft. Detrick, Frederick, MD 21701-5012, Project Order 1812 and U.S. Environmental Protection Agency, Contract 68-02-3800. This manuscript has been reviewed by the Health Effects Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commerical products does not constitute endorsement or recommendation for use.

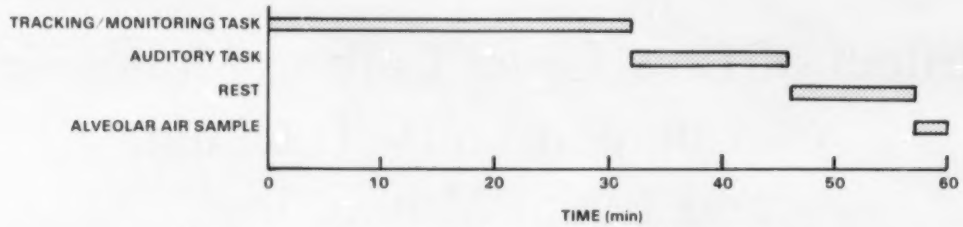

FIG. 1. Temporal order of events during one block of the experiment.

First, the CO levels used are among the lowest CO exposure levels reported to have produced neurobehavioral decrements in healthy young subjects and second, their study appears to be the only neurobehavioral work in the CO literature which has been independently replicated, even by the same investigator. The behaviors which were affected have high face validity as measures of important nonlaboratory tasks such as driving and machine operation, however, the general failure of most studies to find significant effects of exposure to low levels of CO tends to make positive findings less credible. For these reasons, a replication of the above studies by an independent laboratory would further increase their credibility.

METHOD

Experimental Design

Analyses were performed using raw data published by Putz *et al.* [6], as part of the present study, to estimate the power [5] of the significance tests used. The estimated powers were greater when only 0 and 70 ppm groups were used. For 10 subjects per group (0 and 70 ppm), $\alpha = 0.05$, assuming the same size of effect and the same variance as in [6], the CO × Hour effect would be tested with power approaching 1.0. The same test for the light monitoring behaviors would have a power of 0.72.

Based on these calculations, it was decided to test two groups of subjects, control and CO exposed, using 12 subjects per group according to the paradigm and experimental design in [6]. The plan was to collect data from only the tracking and monitoring tasks since the auditory evoked potential results were nonsignificant. Nevertheless, subjects were tested in the tone judgment (evoked potential) task since the performance of the task may have influenced performance on other tasks.

Subjects

Subjects were 24 healthy males who had not smoked for the past five years (self report). The mean age of the group was 24 years (SD = ±2.83, range = 19–31 years). Subjects were paid $5.00 per hour to participate. All subjects had been given examinations by a physician and had made normal scores ±1 S.D. on the Minneapolis Multiphasic Personality Inventory.

Tasks

Tracking task. The tracking task consisted of keeping a focused moving spot (point of light) centered on a CRT by manipulation of a pressure sensitive, nonmoving joystick. All equipment dimensions and calibrations were exactly as reported in [6]. The screen was viewed by the subject by positioning his head in a rubber viewing port, thus fixing the position and distance from eye to screen. In the center of the screen was a circular fixed target consisting of a white ring. A spot on the CRT moved up and down (vertically only) as driven by a forcing function (FF) generated by a microcomputer. The subject's task was to keep the spot inside the clear center of the stationary target by pushing forward or backward on the joystick.

The FF in this task consisted of half sinusoids of one of four amplitudes and either positive (up) or negative polarity. Polarity and amplitude of the FF were independently and pseudorandomly selected for each half cycle. The amplitudes which were used produced ±12.7, ±6.35, ±4.673 and ±3.175 cm of deflection. There were two speeds (and hence difficulties) of the FF, 4 sec/half cycle and 8 sec/half cycle (the "fast" and "slow" speeds). The fast and slow FFs were alternately presented in blocks of trials (see the Procedure section).

Errors were computed as mean absolute deviations (MAD) from target. If no joystick response was made, the MAD score was 1200. A diffused green light was used to illuminate the screen so as to reduce contrast effects. The

TABLE 1

DAILY SCHEDULE OF EVENTS

Time (a.m.)	Event	Cumulative Time
10:00	Prescreened subject arrives	0
10:15	Sign consent forms	15 minutes
10:30	Blood and breath samples collected	30 minutes
10:35	Enter chamber for training*	35 minutes
11:35	Training complete—apply electrodes	1:35 minutes
11:45	Begin tracking/vigilance task†	1:45 hours
12:17	Begin evoked potential (tone) task	2:17 hours
12:31	Begin rest—lunch—breath sample	2:31 hours
12:45	Begin 2nd hour	2:45 hours
1:45	Begin 3rd hour	3:45 hours
2:45	Begin 4th hour	4:45 hours
3:45	Exit chamber—blood sample—debrief	5:45 hours
4:00	Subject leaves	6:00 hours

*Training hour is typical of regular test hour except that verbal feedback is used.

†CO exposure was begun during the first hour of performance immediately after the subject was seated and began the tracking task.

‡Lunch was a standard meal as described in [6].

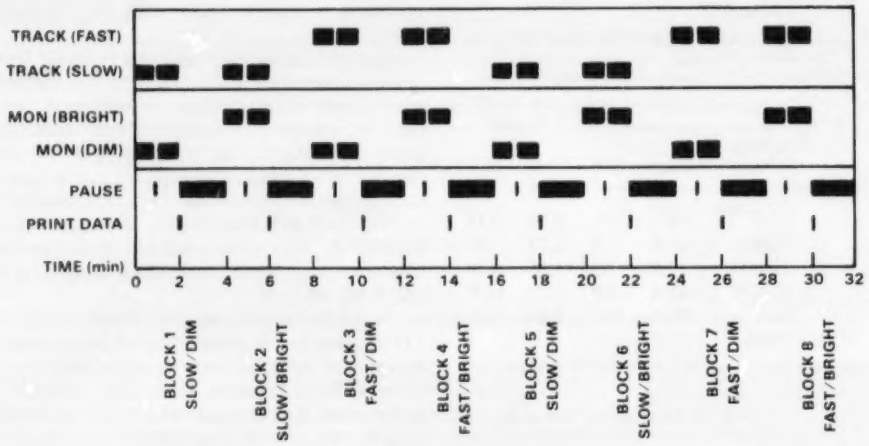

FIG. 2. Temporal order of events during tracking/monitoring task. Four schedules exist depending upon the particular combinations of tracking speed and vigilance brightness which are selected for the first trial. Pause durations: Short=10 sec, Long=118 sec, Trial length=56 sec. Printout occurs after every two trials. Fast forcing function=4 sec/half wave, slow forcing function=8 sec/half wave.

intensity of the light was 0.22 lux (photometer sensor located 6.5 cm from the CRT).

Monitoring task. The monitoring task consisted of monitoring the brightness of two red lights on either side of the CRT. One or the other of these lights was on for 1.5 seconds, and both were then off for 0.74 seconds. The on/off periods were repeated continuously for the duration of the tracking task. Left and right lights were selected pseudorandomly.

Within any block of trials, the red lights were illuminated to either a "dim" or "bright" light level. The subject was required to press a hand-held switch when a relatively brighter light level occurred on either left or right light. On alternate blocks the overall level of illumination was switched between two levels. During the overall bright condition the nonsignal intensity was 0.38 lux and the signal intensity was 1.5 lux. During the overall dim condition the intensities were 0.04 and 0.17 lux. Intensity was measured by placing a photometer sensor 6.5 cm from the lights. Signals and nonsignals were pseudorandomly interspersed. Among every 25 light stimuli, nine were signals.

Auditory task. Electrodes were attached to vertex and linked mastoids of each subject for the third task which was performed in an alternating fashion with the tracking/monitoring task. No data were actually collected, but the task was performed because it was included in the study by Putz *et al.* [6] and it might affect performance of the other tasks.

The auditory task consisted of judging tones presented over a loudspeaker. Each tone had a duration of 1.5 seconds and a loudness of 38 dBA (SPL). The time between tones was 0.75 seconds. The three tone frequencies were 400, 1000 and 2000 Hz. The subject's task was to press a handswitch only when the 1 KHz tone signal was sounded.

Procedure

The schedule of events for a typical day in this experiment is shown in Table 1. Once informed consent and training were completed, the schedule followed an hourly cycle of performance. Figure 1 gives the schedule of events within each hour of performance testing. The tracking/monitoring task was performed first for 32 minutes. Then the subject performed the auditory tone judgment task for 14 minutes, followed by a rest period of 11 minutes, during which the subject was permitted to read. After this, the subject briefly exited from the chamber to have an end-tidal alveolar air sample collected. The cycle was repeated during the subsequent hour.

TABLE 2

DIFFERENCES BETWEEN PRESENT STUDY AND PUTZ *ET AL.* [6]

Parameter	Value in Present Study	Value in Putz *et al.*
Fast FF speed	4 seconds/half cycle	4.28 seconds/half cycle
Slow Ff	8 seconds/half cycle	7.5 seconds/half cycle
Trial length	56 seconds	50 seconds
Interblock	108 seconds	120 seconds
CRT screen size	25.4 cm vertical 20.3 horizontal	25.4 cm square
Monitoring interstimulus interval	0.74 seconds	0.75 seconds
No. of monitoring stimuli per trial	25	22
Monitoring signal/nonsignal ratio	0.36	0.364
Number of subjects per chamber	1	2
Window in chamber	No	Yes
CO level	100 ppm	70 ppm
Subject gender	All males	20 males, 10 females

TABLE 3

FIRST HOUR MEANS AND STANDARD DEVIATIONS FOR SUBJECTS IN AIR EXPOSURE

	Tracking Speed	MAD Scores		Log MAD Scores	
		Mean	SD	Mean	SD
Putz *et al.* [6]	Fast	18.3	2.6	2.90	0.14
	Slow	12.8	2.5	2.53	0.21
Present Study	Fast	17.8	4.5	2.85	0.24
	Slow	12.4	2.8	2.50	0.21
Subsequent Study	Very Fast	590.5	77.3	6.37	0.13

The temporal order of events within tracking/monitoring task was complex (see Fig. 2). Performance was divided into 56 second trials. Two trials formed a block, with 8 blocks in the 32 minute performance period. Blocks were separated by 118 second pauses. Trials were separated from each other (within blocks) by a 10 second pause.

Monitoring behavior alternated in a blockwise fashion between the overall bright and dim conditions. Tracking FF speed alternated between fast and slow on a two-block cycle. Thus, each block had a bright or dim (monitoring) condition and a fast or slow (tracking) condition. Within a 32 minute performance period, each combination of conditions occurred twice.

Differences from Putz et al. *[6].* Despite major efforts to make this replication exact, several differences were found to be necessary or extremely convenient. The differences are summarized in Table 2. Most of the differences were trivial in nature. A possibly major difference between the present study and that of [6] was that they tested two subjects simultaneously in the same chamber. In the present study, for logistic reasons, only one subject was studied at a time in a visually and acoustically isolated chamber. In [6], the two subjects were tested alternately, one during the resting time of the other. The possible social contact between subjects, even without transmission of information about performance, could have affected baseline values. The mixed gender group of subjects in [6] also could make differences in performance level.

Double blind design. This study was entirely double blind. CO level was determined by a pseudorandom schedule. Chamber concentration of CO was monitored by one of the senior investigators who had no contact with the subject. Other investigators remained blind until after the completion of the experiment for that subject.

Statistics. Planned *a priori* hypotheses were formed [4]. Two dependent variables were to be tested: (a) MAD scores for the tracking task and (b) response time for the peripheral light task. Univariate repeated measures analysis [2] was used for both tasks. Each analysis is detailed below.

For the tracking task variable, a CO × FF speed × duration-of-exposure factorial design (2×2×4) was used. CO is a "between" factor and the other two are "within" factors. Levels were 0 and 100 ppm CO and one, two, three and four hours of exposure.

For the peripheral light task, CO and duration of exposure (2×4) were the factors, with levels as above. A factorial model was tested, again with CO "between" and Hour "within."

For both analyses, stepdown tests [2] were to be done as separate tests for each hour. If the three-way interaction were involved in tracking, second level stepdowns were to be CO within FF speed. Three differences exist from analyses in [6]: (a) the dropping of the 35 ppm CO level, (b) the use of a Geisser-Greenhouse correction for F tests, and (c) a Bonferroni correction [4] to evaluate each overall test at $\alpha=0.05/2=0.025$. Stepdowns, if needed, were to be tested at $\alpha=0.025/k$, with k=number of stepdowns within the family. These choices were made after using data from [6] for exploratory analysis.

In the initial analysis plan, MAD scores were to be used. Subsequent to the completion of the present experiment and analysis of the data, another study was conducted utilizing a more difficult tracking task. The rationale for the second experiment was to study the effect of a more difficult FF. Another variable was the statistical structure of the FF in the subsequent study. The results from this subsequent study provided further insight to the analysis of the data from the present study.

Table 3 shows the first hour means and standard deviations from [6], the present study and from the subsequent study. Inspection of Table 3 reveals that the standard deviations are proportional to the means. Further inspection of distributions and regression diagnostics led to the conclusions that for MAD scores, errors were multiplicative rather than additive. Careful inspection of data within each study revealed similar patterns but since the range of data was small within each study, the patterns were not nearly so obvious. The usual solution, logarithmic transformation, was applied here. Table 3 includes the means and standard deviations after natural log transformation of MAD scores. The transformation eliminated the proportionality of standard deviations to means and also produced more appealing regression diagnostics. It was impressive that all three studies produced data of similar variances despite the fact that one of the three used a more difficult task and was also different in design. Such generality leads to the conclusion that the logarithm transform is appropriate for tracking MAD scores. Hence the present data were reanalyzed, and are therefore presented here as log MAD scores.

COHb. Two three ml vacutainers of blood were drawn, as shown in Table 1, before and after exposure. COHb values were measured in triplicate, immediately after blood was drawn, for each sample by use of an Instrumentation Laboratories model 282 CO oximeter. Triplicate values were averaged to provide a final pre and post COHb value. Alveolar air samples were not analyzed to minimize the number of dependent variables in this study.

RESULTS

COHb

Table 4 shows the results of the COHb analyses. These were well within expected limits.

Subject Selection

Two subjects were eliminated from the analyses. One of them failed to complete the task, an air subject, and the other's performance, a CO subject, was much worse than the rest of the subjects'. The latter subject's performance was more than four standard deviations from the mean when the

TABLE 4

MEAN, SD AND RANGE OF COHb, IN PERCENT, FOR EXPOSED AND CONTROL GROUPS, BEFORE AND AFTER EXPOSURE TO 100 PPM CO FOR FOUR HOURS

	Before Exposure Period		After Exposure Period	
Control Group	M=1.42	SD = ±0.39 range=0.9–2.32	M=1.22	SD = ±0.24 range=0.87–1.55
Exposed Group	M=1.36	SD= ±0.18 range=1.07–1.57	M=8.24	SD = ±0.49 range=7.57–9.03

TABLE 5

MEANS AND STANDARD DEVIATIONS OF ln(MAD) (PRESENT STUDY)

	Slow FF		Fast FF	
	Air	CO	Air	CO
HR1	2.50 ± 0.212	2.47 ± 0.333	2.85 ± 0.236	2.90 ± 0.241
HR2	2.46 ± 0.237	2.45 ± 0.335	2.88 ± 0.196	2.88 ± 0.230
HR3	2.38 ± 0.255	2.45 ± 0.243	2.85 ± 0.208	2.95 ± 0.210
HR4	2.34 ± 0.195	2.51 ± 0.322	2.74 ± 0.247	2.92 ± 0.230

TABLE 6

SIGNIFICANCE TESTS FOR ln(MAD) SCORES USING GEISSER-GREENHOUSE ADJUSTED DEGREES OF FREEDOM* (PRESENT STUDY)

Effect	F	ϵ†	df_1, df_2*	p
CO	0.48	—	1, 20	0.4966
FF Speed	371.61	—	1, 20	0.0000†
Time (of exposure)	1.13	0.86	2.6, 51.9	0.3411
CO × Speed	0.49	—	1, 20	0.4908
CO × Time	4.51	0.86	2.6, 51.9	0.0095†
Time × Speed	1.85	0.83	2.5, 49.6	0.1588
CO × Time × Speed	0.35	0.83	2.5, 49.6	0.7499

†$p<0.025$.

‡ϵ is the Geisser-Greenhouse estimated correction factor. Application of ϵ may result in fractional degrees of freedom.

group statistics had been computed after his removal. No other subject was even close to such an extreme score. Since the latter was a CO subject, his elimination only lessened the possibility of a CO effect. Thus the statistical tests reported in this section are based on 22 subjects, and are conservative with respect to a CO effect.

Tracking

Present study. In the initial confirmatory analysis, no significant CO effect was found, even though trends in means could be interpreted to agree with the findings of Putz *et al.* [6]. The test of most interest in the initial analysis (CO × Hour) gave a $p=0.035$, thereby failing to achieve the *a priori* α of 0.025. Reanalysis using ln(MAD) score (see the Method section for rationale) produced different results. Table 5 gives the means and standard deviations of the ln(MAD) scores and Table 6 gives the corresponding significance tests. The CO × hour of exposure test gives $p<0.01$, which was less than the required 0.025, implying that the ln(MAD) scores significantly diverged as a function of time of CO exposure. Figures 3A, C and 4A lead to the conclusion that COHb produced a larger ln(MAD) score than the control group. Planned stepdown tests for each hour comparing air and CO exposed groups were not significant, giving p values of 0.9434, 0.9465, 0.3693 and 0.1062, while the criterion was $\alpha=0.00833$. *Post hoc* exploratory analysis revealed that the CO × Hour interaction appeared to be a linear trend ($p<0.0089$). Quadratic and cubic trends had associated p values of 0.2135 and 0.4383, respectively.

Reanalysis of Data From Putz et al. *[6]*

In order to make comparisons to [6], data from their study were reanalyzed using ln(MAD) scores. Tables 7 and 8 give summary statistics and significance tests. Inspection of Table 8 shows that the three-way interaction term was statistically significant. The stepdown test of CO by Hour for the slow FF gave, $F(3,16)=2.34$, $p=0.1114$, while the test for the fast FF gave $F=23.33$, $p<0.0002$. The second level stepdowns were air vs. CO tests at each hour for the fast FF, with p values of 0.3455, 0.1348, 0.0090 and <0.0001, for t with 18 *df*. Inspection of Fig. 3B and C lead to the descriptive conclusion that the CO effect was greater for fast FF tracking than for slow FF tracking [6]. Inspection of Figures 3B, D and 4B reveal that CO exposure significantly increased ln(MAD) scores after sufficient exposure time.

Comparison of Present Study to Putz et al.

Figures 3A–4B were prepared to facilitate comparison of

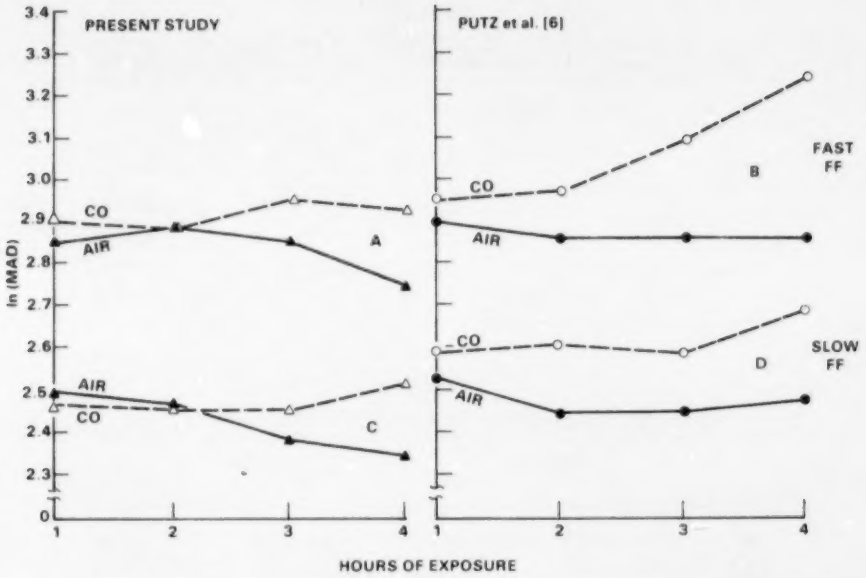

FIG. 3. Graphs of ln(MAD) scores for the present study (A and C) and for the study by Putz *et al.* [6] (B and D). A and B are for the fast FF and C and D are for the slow FF.

TABLE 7

MEANS AND STANDARD DEVIATIONS OF ln(MAD) SCORES (PUTZ *ET AL.*)

	Slow FF		Fast FF	
	Air	CO	Air	CO
HR1	2.53 ± 0.213	2.59 ± 0.137	2.90 ± 0.144	2.95 ± 0.094
HR2	2.44 ± 0.247	2.61 ± 0.166	2.86 ± 0.182	2.97 ± 0.139
HR3	2.45 ± 0.258	2.58 ± 0.144	2.86 ± 0.198	3.09 ± 0.156
HR4	2.47 ± 0.240	2.69 ± 0.127	2.85 ± 0.164	3.24 ± 0.133

TABLE 8

SIGNIFICANCE TESTS FOR ln(MAD) SCORES USING GEISSER-GREENHOUSE ADJUSTED DEGREES OF FREEDOM* FROM PUTZ *ET AL.* [6]

Effect	F	ϵ†	df_1, df_2*	p
CO	5.87	—	1, 18	0.0262
FF Speed	310.81	—	1, 18	0.0001
Time (of exposure)	11.60	0.97	2.9, 52.6	0.0001
CO × Speed	1.28	—	1, 18	0.2732
CO × Time	18.01	0.97	2.92, 52.57	0.0001
Time × Speed	4.80	0.71	2.12, 38.15	0.0124
CO × Time × Speed	4.79	0.71	2.12, 38.15	0.0126

†ϵ is the Geisser-Greenhouse estimated correction factor. Application of ϵ may result in fractional degrees of freedom.

results from the present study with those of [6]. Figure 3A–D illustrate the results for fast and slow FFs separately for the two studies. The significant three-way interaction term in the reanalysis of the Putz *et al.* [6] data makes this separation necessary.

Figure 4A and B were produced by averaging ln(MAD) scores for the fast and slow FF conditions separately for the air and CO groups. This is acceptable even in the face of the significant three-way interaction for the data from [6], since the interaction was ordinal (i.e., direction of effect was the same for both fast and slow FF).

Monitoring

Table 9 gives the significance tests for the peripheral light monitoring task. No test was statistically significant. Figure 5 gives the mean reaction times over the four hours of performance and exposure for both the data from [6] and the data from the present study. The mean reaction time from the present study was lower than in [6] and the mean squared error was 775 from [6] and 1423 for the present study.

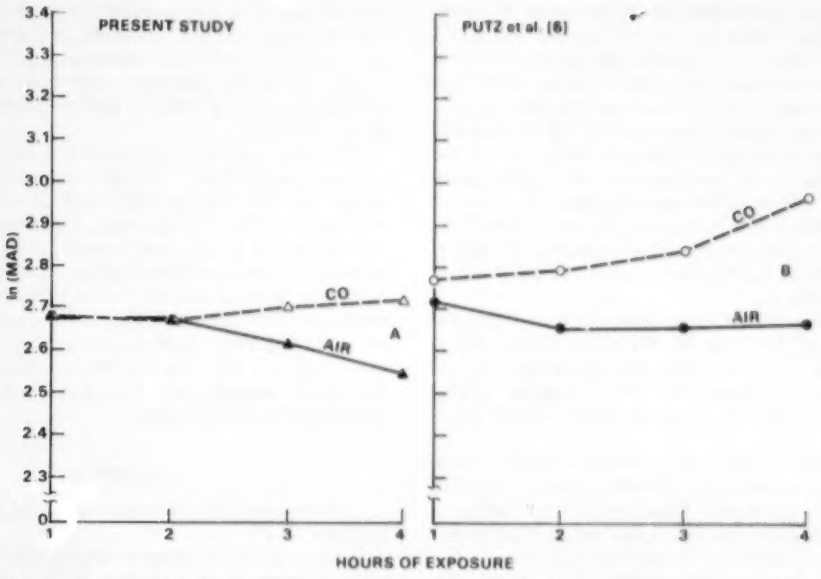

FIG. 4. Graphs of effects due to COHb averaged across task difficulty for present study (A) and for Putz *et al.* [6] (B).

TABLE 9

SIGNIFICANCE TESTS FOR MONITORING TASK USING GEISSER-GREENHOUSE CORRECTED DEGREES OF FREEDOM*

Effect	F	ϵ†	df_1, df_2*	p
CO	0.29	—	1, 20	0.60
Time	1.11	0.64	1.9, 38.5	0.34
CO × Time	0.96	0.64	1.9, 38.5	0.39

†ϵ is the Geisser-Greenhouse estimated correction factor. Application of ϵ may result in fractional degrees of freedom.

DISCUSSION

Tracking

In both [6] and the present study, it was found that CO exposure produced larger compensatory tracking error than laboratory air breathing in healthy young men, given sufficient CO exposure time. Data from [6], however, illustrated that the greater task difficulty (FF speed) produced larger CO effects than the slower FF speed. This finding was not confirmed in the present study. Comparison of descriptive data of Fig. 3A and B reveals that a major difference between the two studies occurred in the third and fourth hours of exposure. In [6] the ln(MAD) scores for the faster FF, CO exposed subjects increased more than in the present study. The question of an interaction of task difficulty with CO exposure remains unresolved.

In Fig. 4A and B, the ln(MAD) score curves diverged over time of exposure between air and CO groups. The effect appears to be larger for the data from [6] than for the present study. Another difference between studies was that in the

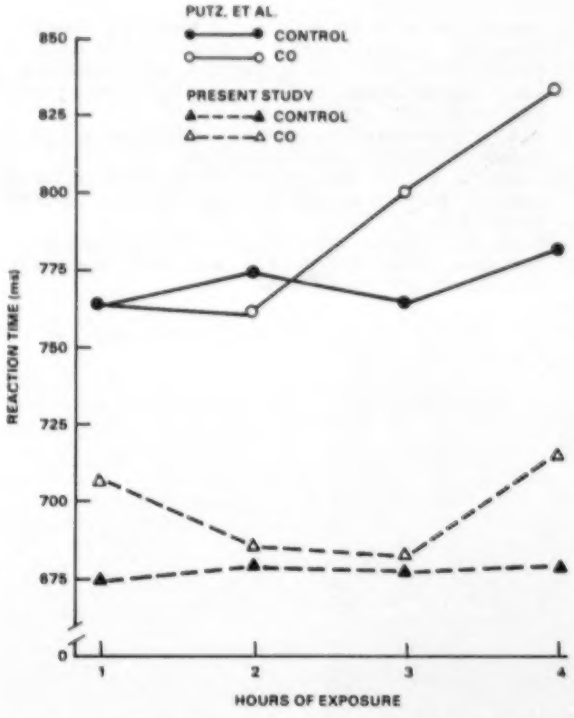

FIG. 5. Monitoring performance means for the present study and for data from the study by Putz *et al.* [6] (Fig. 2).

present study, the air group scores continued to improve, implying that subjects were not as well trained as in [6]. Conversations with Putz *et al.* verified that indeed the training of their subjects was more extensive than was implied in [6]. The latter observation might mean that the effect of CO in the present study was partly on acquisition of the task and partly on purely performance parameters, while in [6] the effect was more purely on performance. Such differences might explain the minor difference between the present study and [6]. Further discussion of this issue would be speculative since no data are available regarding the difference between the results of the two studies and the possible cause of this difference.

The mean COHb in the CO exposed group was 8.24% for the present study and 5.1% for [6]. When the COHb difference is considered, it is surprising that the effects in the present study were not larger than those reported in [6]. Without further research the problem must remain unresolved.

Even though some differences between studies have emerged, the findings agree that a CO effect occurs at COHb levels of between 5.1 and 8.24%. Confidence in the finding of impairment of compensatory tracking by low level CO exposure is increased as a result of the present findings.

It is important to note that neither the findings reported in [6] nor the findings of the present report provide any detail about the mechanism of the behavioral decrement. It is possible that the human operator's response time was slowed, that he began to make irrelevant responses (noise) or that he began to under-respond, or some of each. Information about the particular behavioral ability which was impaired would help theorists understand the central nervous system effects of COHb as well as permit generalization to other behaviors.

The facts that the reaction times in the present study were so much faster than in [6] and that variability was greater, temper the fact that no significant CO effect on monitoring was found in the present study. For some unknown reason, the task in the present study was easier. Other differences could have existed thus mitigating against replication, e.g., a difference in instructions to the subject as to the relative emphasis of the simultaneous tasks. The fact of large variability in the present data suggest the subjects were less well trained than in [6]. The possible social interaction between two simultaneously tested subjects in [6] might also have contributed to differences.

SUMMARY

1. Exposure to CO for four hours impaired compensatory tracking.

2. Magnitude of relative impairment reported here was less than that reported by Putz *et al.* [6] even though COHb levels were higher in the present study (8.24% vs. 5.1%).

3. It is unclear whether the size of the COHb effect was related to task difficulty.

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